

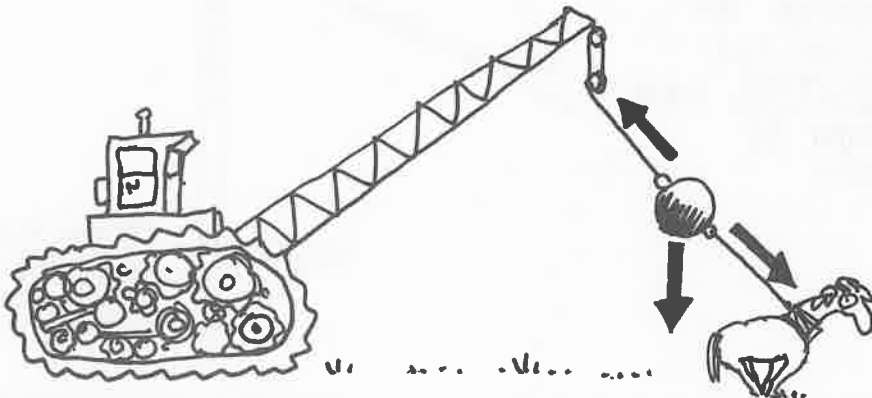
# ♦ CHAPTER 7 ♦ MORE ABOUT FORCES



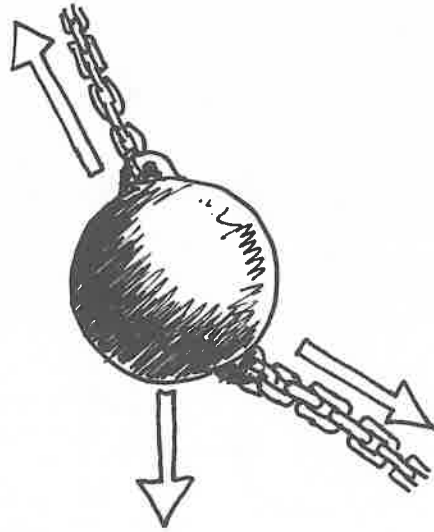
NEWTON'S LAWS CAN BE THOUGHT OF AS DESCRIBING WHAT FORCES DO:

1. WITHOUT ANY FORCES, OBJECTS MAINTAIN CONSTANT VELOCITY.
2. A FORCE PRODUCES AN ACCELERATION PROPORTIONAL TO THE FORCE (AND INVERSELY PROPORTIONAL TO THE MASS.)
3. OBJECTS EXERT EQUAL BUT OPPOSITE FORCES ON EACH OTHER.

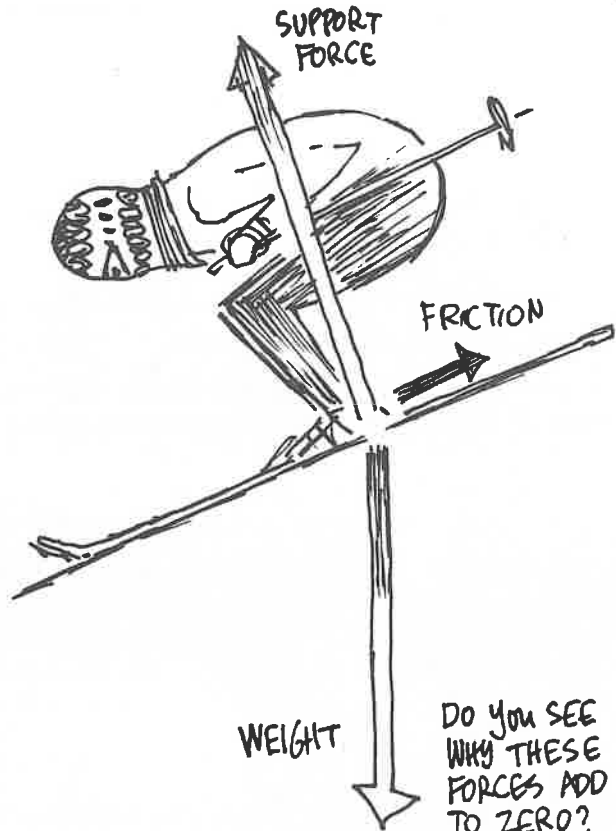
FORCE IS A "VECTOR QUANTITY." LIKE VELOCITY AND ACCELERATION, IT HAS NOT ONLY A **MAGNITUDE** BUT ALSO A **DIRECTION**. IN THIS PICTURE, FORCES PULL IN SEVERAL DIFFERENT DIRECTIONS.



BUT IN THIS CASE, THE SUM OF ALL THE FORCES, THE NET FORCE, IS ZERO, BECAUSE THE MASS IS NOT ACCELERATING. (NEWTON'S SECOND LAW AGAIN!)



CONSIDER THE FORCES ON A SKIER MOVING DOWN A HILL AT CONSTANT SPEED. THERE ARE HER WEIGHT, THE SUPPORT OF THE GROUND, AND THE FORCE OF FRICTION. BUT AGAIN, THE TOTAL FORCE MUST BE ZERO.

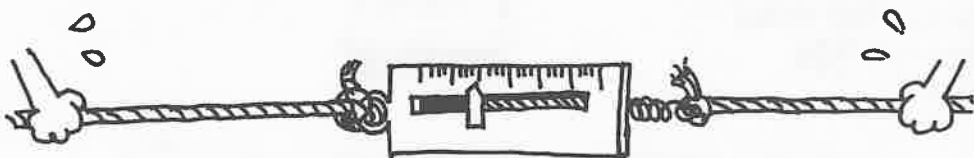


DO YOU SEE WHY THESE FORCES ADD TO ZERO?

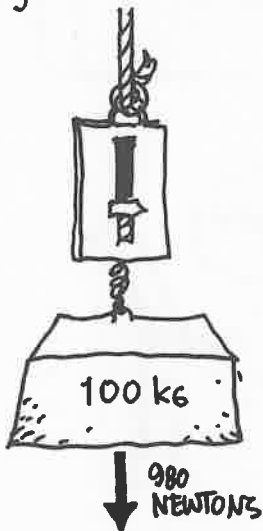
NOW IMAGINE A TUG OF WAR IN WHICH EACH TEAM PULLS WITH A FORCE OF 980 NEWTONS. WHAT IS THE TENSION IN THE ROPE? IS IT  $2 \times 980 = 1960$  NEWTONS?



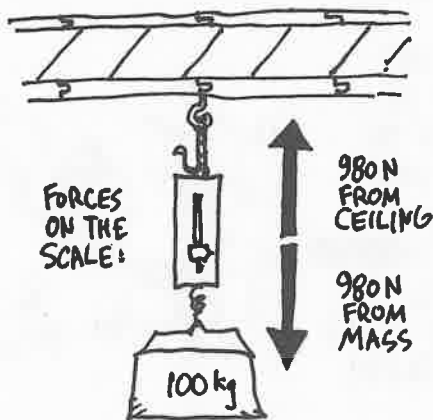
THE TENSION IS DEFINED AS THE VALUE A SPRING SCALE WOULD READ IF THE ROPE WERE CUT AND THE SCALE INSERTED:



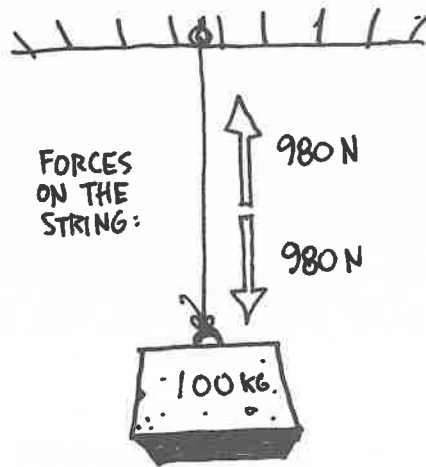
YOU MIGHT WANT TO COMPARE THIS SITUATION TO WEIGHING A 100-kg MASS WITH A SPRING SCALE. THE MASS HAS A WEIGHT OF 980 NEWTONS ( $=mg$ ).



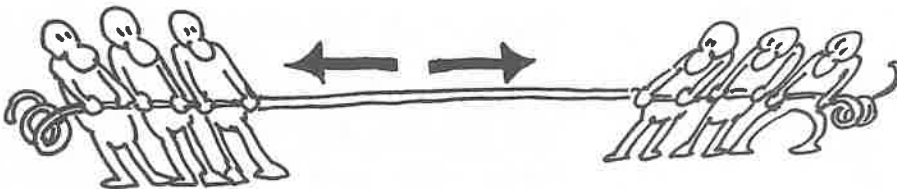
THE MASS PULLS DOWN ON THE SCALE WITH A FORCE OF 980 NEWTONS, SO THE SCALE PULLS UP ON THE MASS WITH THE SAME FORCE. THEN THE SCALE ALSO PULLS DOWN ON THE CEILING, AND THE CEILING PULLS BACK WITH 980 NEWTONS FORCE!



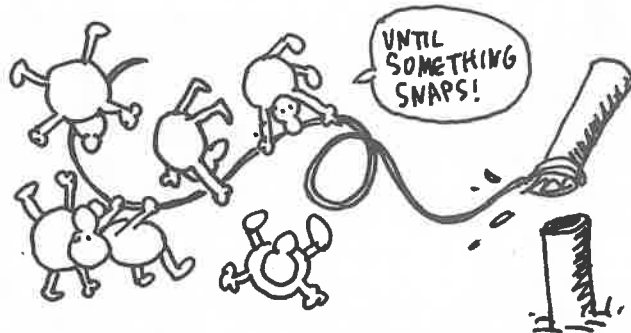
IN EFFECT, THE STRING TRANSMITS THE FORCE FROM THE MASS THROUGH THE SCALE TO THE CEILING. THE MASS AND THE STRING PULL ON EACH OTHER EQUALLY, BY NEWTON'S THIRD LAW, AND THE TENSION ON THE STRING - THE SCALE READING - IS 980 NEWTONS.

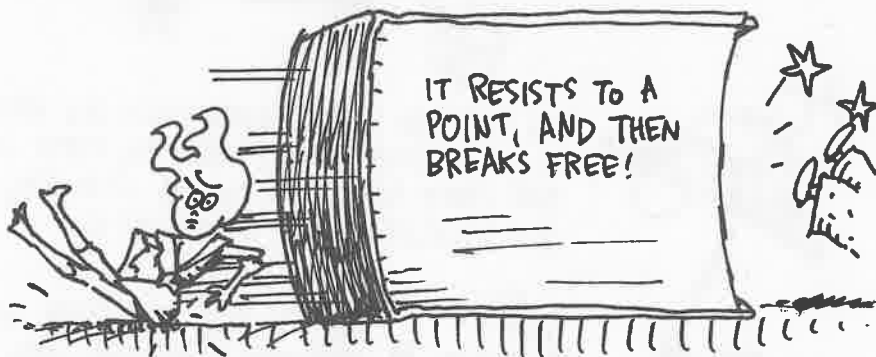
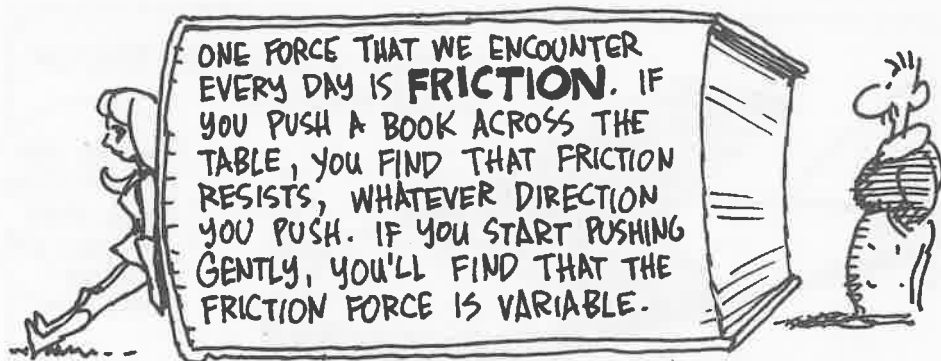


DOES THIS CONVINCE YOU THAT THE TENSION IN THE TUG-OF-WAR ROPE IS ALSO 980 NEWTONS? THE ROPE TRANSMITS THE FORCE FROM ONE TEAM TO THE OTHER.

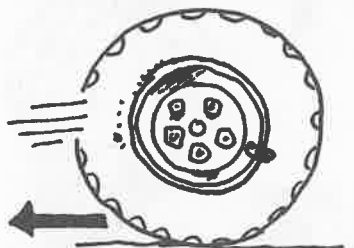


IF YOU TIED ONE END OF THE ROPE TO A POST, AND BOTH TEAMS PULLED TOGETHER, THEN THE TENSION WOULD BE DOUBLED!

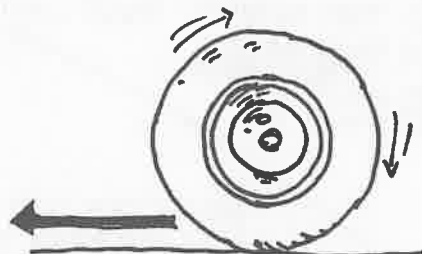




CAN YOU FEEL THAT FRICTION DECREASES SLIGHTLY AS THE BOOK STARTS TO MOVE? WE SAY THAT THE **STATIC** FRICTION, WHEN THE SURFACES ARE STATIONARY, VARIES UP TO A MAXIMUM VALUE. THE **KINETIC** FRICTION, WHEN THEY ARE MOVING, IS LESS THAN THE MAXIMUM STATIC FRICTION. THAT'S WHY A SKIDDING CAR TAKES LONGER TO STOP THAN ONE WHOSE WHEELS ARE ROLLING.



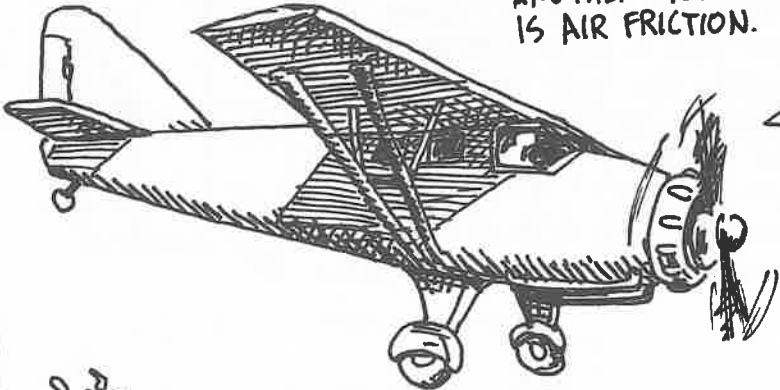
SKIDDING TIRE SLOWED BY KINETIC FRICTION



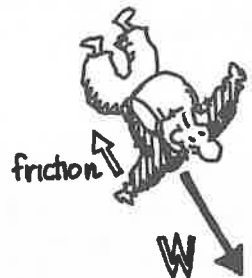
ROTATING TIRE'S POINT OF CONTACT IS MOMENTARILY STATIONARY (!), SO THE TIRE IS SLOWED BY STATIC FRICTION.

ANOTHER EXAMPLE OF FRICTION IS AIR FRICTION.

YOU CAN FEEL IT BY STICKING YOUR HAND OUT YOUR CAR WINDOW!

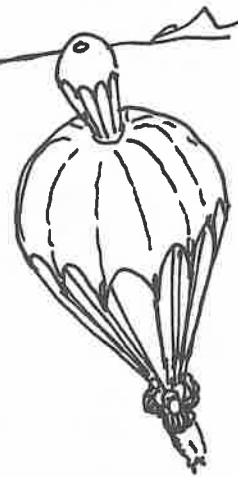


AN EXCITING WAY TO EXPERIENCE AIR FRICTION IS TO GO SKYDIVING. WHEN YOU FIRST JUMP, THE ONLY FORCE ON YOU IS GRAVITY, AND YOU ACCELERATE AT A RATE OF  $g$ .



AS YOU PICK UP SPEED, AIR FRICTION INCREASES, AND YOUR ACCELERATION SLOWS.

EVENTUALLY, AT 100-150 MPH, THE AIR FRICTION EQUALS YOUR WEIGHT, AND YOUR SPEED INCREASES NO FURTHER. WE CALL THIS NATURAL SPEED LIMIT YOUR **TERMINAL VELOCITY**.



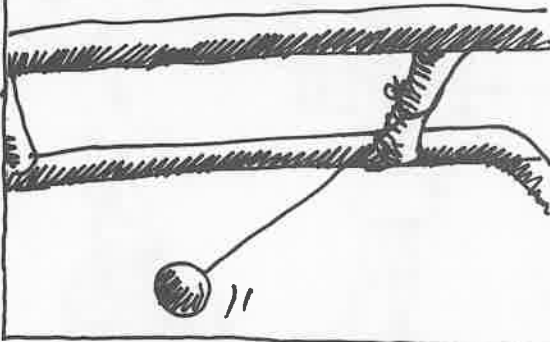
AIR FRICTION ALSO DEPENDS ON THE AREA "FRONTING THE WIND," WHICH IS WHY A PARACHUTE CAN SLOW YOUR TERMINAL VELOCITY TO 25 MPH OR SO.

# SOME FORCES ARE

# FICTITIOUS



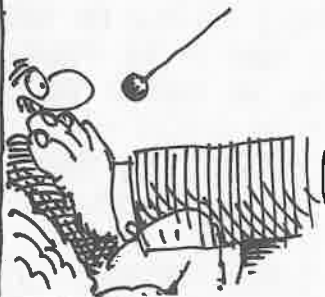
RECALL THE ACCELEROMETER BALL WE HUNG FROM RINGO'S ROLL BAR? IT HANGS BACKWARD WHEN HE ACCELERATES. BUT WHY?



THERE ARE ONLY TWO REAL FORCES ON THE BALL: GRAVITY, WHICH PULLS DOWNWARD WITH MAGNITUDE  $mg$ , AND THE TENSION  $T$  ON THE STRING. WHEN RINGO ACCELERATES, THE TOTAL OF THESE TWO MUST POINT FORWARD WITH MAGNITUDE  $ma$ , BY NEWTON'S SECOND LAW — SO THE STRING MUST HANG AT AN ANGLE.



BUT RINGO, IN THE CAR, IMAGINES A STRANGE "ACCELERATION FORCE" PUSHING EVERYTHING BACKWARDS!

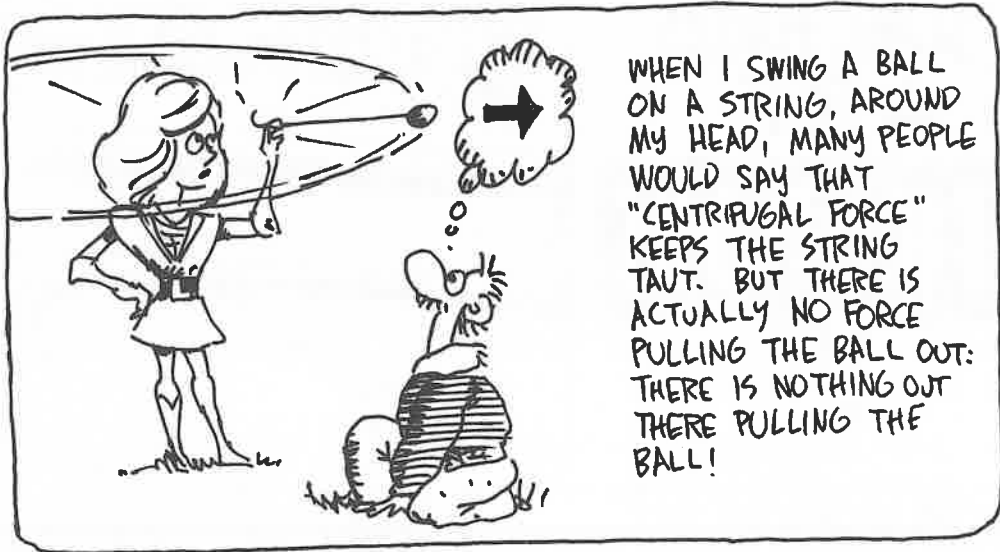


BUT THERE IS NOTHING DOING THE PUSHING. THE "FORCE" IS FICTITIOUS, AN EFFECT OF **INERTIA** RESISTING THE CAR'S ACCELERATION.

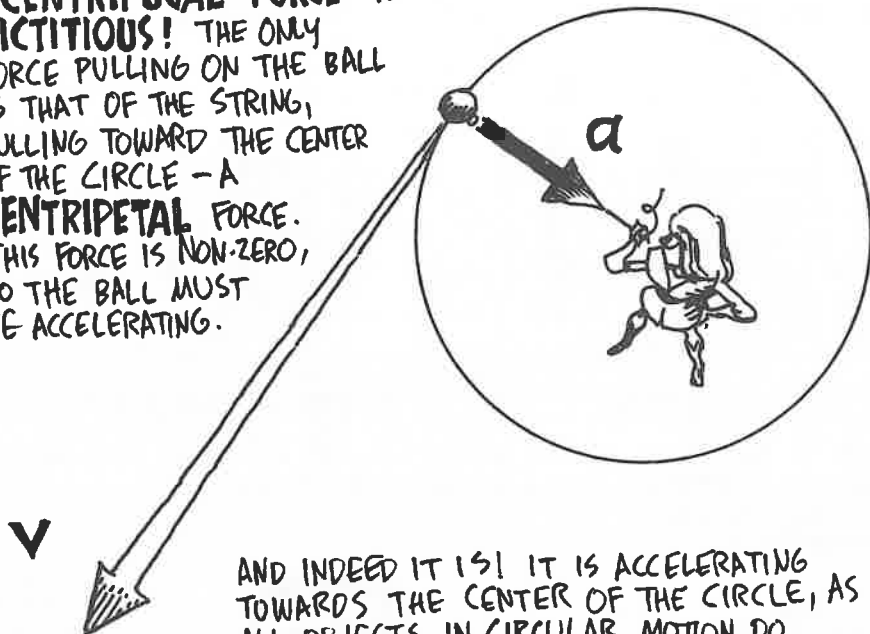


ALL THE SIDEWAYS AND BACK-AND-FORTH FORCES YOU FEEL WHILE DRIVING ARE FICTITIOUS, THE RESULT OF YOUR INERTIA RESISTING ACCELERATION.





"CENTRIFUGAL FORCE" IS FICTITIOUS! THE ONLY FORCE PULLING ON THE BALL IS THAT OF THE STRING, PULLING TOWARD THE CENTER OF THE CIRCLE - A **CENTRIPETAL** FORCE. THIS FORCE IS NON-ZERO, SO THE BALL MUST BE ACCELERATING.



AND INDEED IT IS! IT IS ACCELERATING TOWARDS THE CENTER OF THE CIRCLE, AS ALL OBJECTS IN CIRCULAR MOTION DO. WHAT KEEPS THE STRING TAUT? THE BALL'S **INERTIA**. THIS INERTIA WOULD MAKE IT FLY TANGENTIALLY AWAY, BUT THE STRING PULLS IT CONTINUALLY INWARD - JUST LIKE THE EARTH PULLING THE MOON IN A CIRCULAR ORBIT.

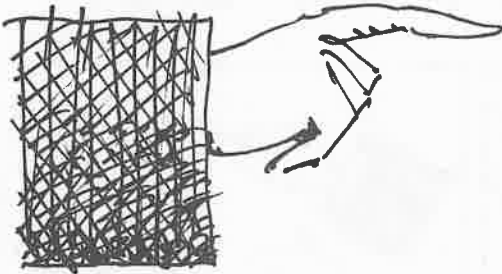


AN AMUSEMENT  
PARK OFFERS  
SEVERAL FICTITIOUS  
FORCES. LOOK AT  
THE **ROTOR**:

PEOPLE ENTER A  
CYLINDER, WHICH  
ROTATES, PRESSING  
THEM AGAINST  
THE WALL—THEN  
THE FLOOR  
DROPS AWAY,  
LEAVING THEM  
PINNED TO  
THE WALL!



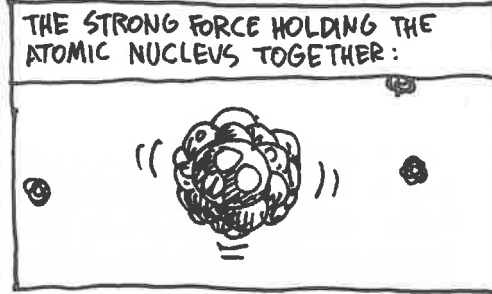
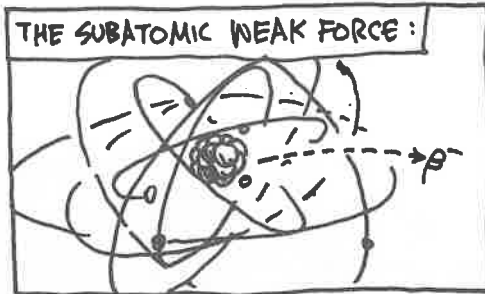
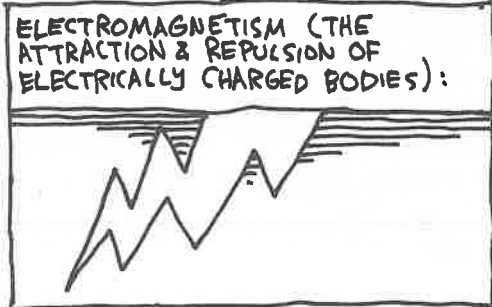
THE PEOPLE INSIDE THE ROTOR FEEL  
THE FICTITIOUS **CENTRIFUGAL**  
FORCE PUSHING THEM OUTWARD.  
BUT OUTSIDE OBSERVERS KNOW  
THERE IS ONLY A **CENTRIPETAL**  
FORCE FROM THE WALL, PUSHING  
THE RIDERS INWARD INTO  
CIRCULAR MOTION.



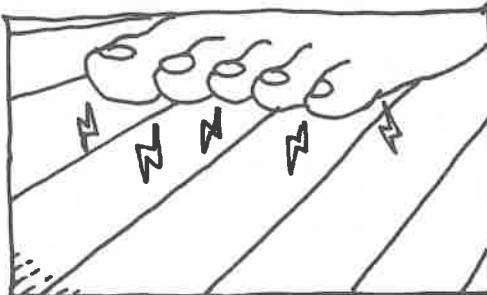
IN AN ACCELERATING  
SYSTEM (ROTATING HERE)  
FICTITIOUS FORCES  
APPEAR. A NON-  
ACCELERATING OBSERVER  
CAN DESCRIBE THE  
MOTION WITH REAL  
FORCES AND NEWTON'S  
LAWS.

WE SEE SUCH A VARIETY OF FORCES, THAT IT MAY SEEM HOPELESS TO TRY AND ORGANIZE THEM. NEVERTHELESS, PHYSICISTS HAVE BEEN ABLE TO SHOW THAT **ALL** THE KNOWN EFFECTS IN THE UNIVERSE ARE THE RESULT OF THESE

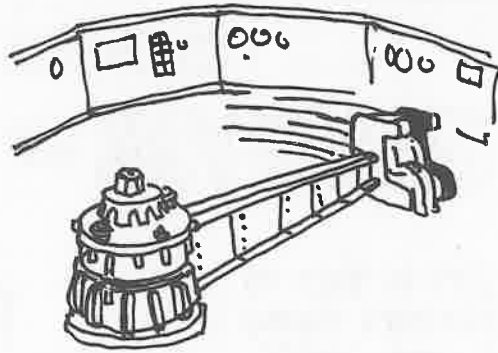
# 4 BASIC FORCES:



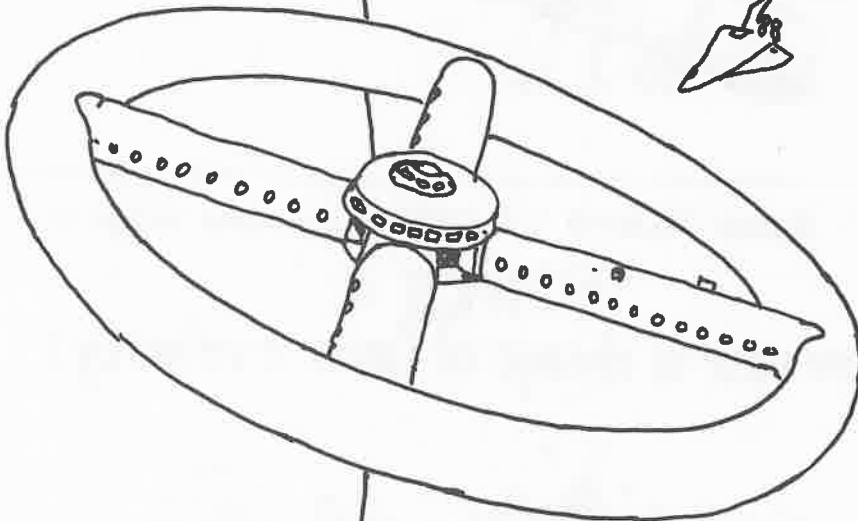
BY THE WAY, THE ONLY ONE OF THE BASIC FORCES YOU'VE EVER FELT IS ELECTROMAGNETISM!! WHEN YOU PUSH THE WALL (AND IT PUSHES BACK), YOU'RE FEELING ELECTRIC REPULSION BETWEEN ATOMS. YOU HAVE NEVER FELT GRAVITY — ONLY THE ELECTRIC FORCES OF THE FLOOR THAT SUPPORT YOU AGAINST GRAVITY.



THE "CENTRIFUGAL FORCE" RESEMBLES GRAVITY IN THAT IT PRODUCES ACCELERATIONS INDEPENDENT OF THE MASSES INVOLVED. THAT'S WHY WE CAN SIMULATE GRAVITY WITH THIS BIG CENTRIFUGE USED IN ASTRONAUT TRAINING:



SOMEDAY, WE MAY EVEN BUILD A ROTATING SPACE STATION WITH THE "CENTRIFUGAL FORCE" PROVIDING AN ARTIFICIAL GRAVITY.

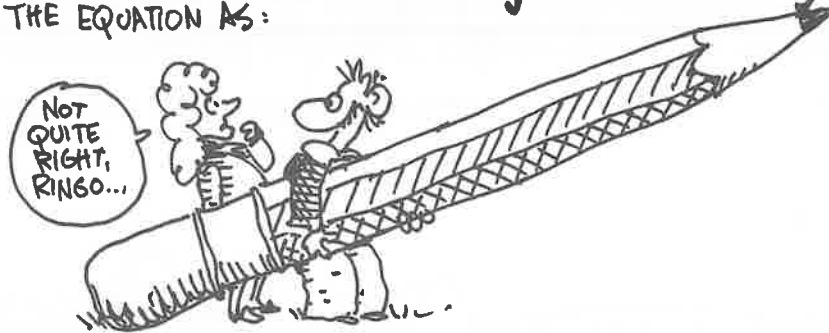


SLOW IT DOWN! I'M TRYING TO LOSE WEIGHT.

◇ CHAPTER 8 ◇  
**MOMENTUM AND IMPULSE**

LET'S GO BACK TO  
NEWTON'S SECOND LAW,  
 $F = ma$ . SINCE  
ACCELERATION IS THE  
RATE OF CHANGE OF  
VELOCITY OVER TIME,  
WE CAN RE-WRITE  
THE EQUATION AS:

**FORCE =**  
mass  $\times$  (time rate of  
change of velocity)



BUT NEWTON BELIEVED THE CORRECT EQUATION SHOULD BE:

**FORCE =**  
time rate of change of (mass  $\times$  velocity).



WHICH IS THE SAME ONLY IF MASS DOESN'T CHANGE!

WE CALL THE QUANTITY  
MASS  $\times$  VELOCITY THE  
**MOMENTUM.**

THE EQUATION SAYS THAT  
FORCE DEPENDS ON THE RATE  
OF CHANGE OF MOMENTUM.



AN OBJECT WITH SMALL  
MASS AND MODERATE SPEED,  
LIKE A RUNAWAY BABY  
CARRIAGE, HAS ONLY  
MODERATE MOMENTUM.  
IT DOESN'T REQUIRE MUCH  
FORCE TO CHANGE ITS  
MOMENTUM TO ZERO  
(I.E., TO STOP IT).



A RUNAWAY MACK TRUCK,  
ON THE OTHER HAND...





LET'S THINK FOR A MOMENT ABOUT THE PERIOD OF TIME IT TAKES TO SLOW THE TRUCK TO ZERO. OUR EQUATION IS:

$$\text{FORCE} = \text{RATE OF CHANGE OF MOMENTUM}$$

$$\text{FORCE} = \frac{\text{CHANGE IN MOMENTUM}}{\text{TIME}}$$

OR

$$\text{FORCE} \times \text{TIME} = \text{CHANGE IN MOMENTUM}$$

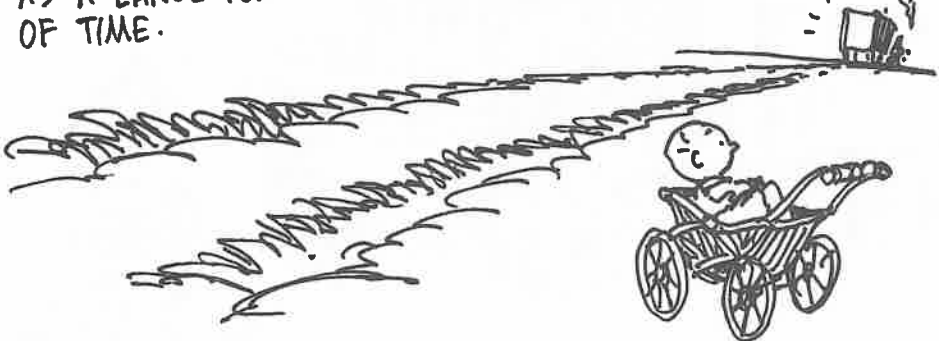
YOU **COULD** STOP THE RUNAWAY TRUCK WITH YOUR RELATIVELY PUNY FORCE — **IF** YOU EXERT IT OVER A LONG PERIOD OF TIME.



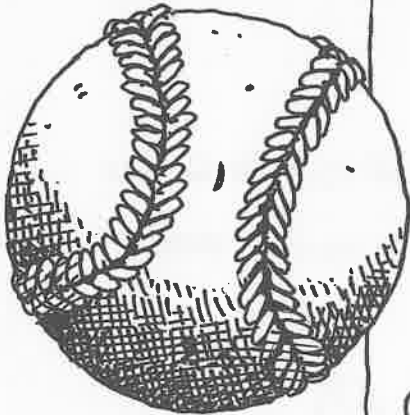
WE CALL THE QUANTITY  $\text{FORCE} \times \text{TIME}$  THE **IMPULSE**.

SO: **IMPULSE = CHANGE OF MOMENTUM.**  
A SMALL FORCE OVER A LONG PERIOD OF TIME CAN PRODUCE THE SAME CHANGE IN MOMENTUM AS A LARGE FORCE OVER A SHORT PERIOD OF TIME.

OOOH...ARE MY FEET **HOT**...

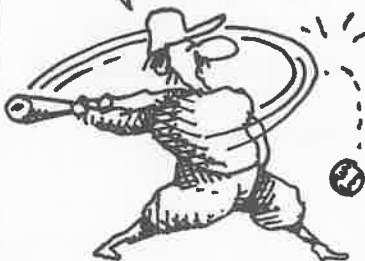


USUALLY WE THINK OF IMPULSE AS A LARGE FORCE ACTING OVER A SHORT TIME, LIKE A BAT HITTING A BALL.



THE BATTER'S JOB IS TO CHANGE THE BALL'S MOMENTUM FROM MEDIUM IN ONE DIRECTION TO HIGH IN THE OPPOSITE DIRECTION. SINCE THE BAT MEETS THE BALL FOR ONLY A SPLIT SECOND, THE FORCE MUST BE VERY LARGE.

GET ME STEROIDS!



SOMETIMES WE WANT TO MINIMIZE THE FORCE NEEDED TO CHANGE MOMENTUM. A SKYDIVER, EVEN WITH A PARACHUTE, STILL HITS THE GROUND WITH MODERATE MOMENTUM.



WHAT'S THAT BIG BASEBALL?



IF SHE LANDS WITH KNEES LOCKED, HER MOMENTUM DROPS TO ZERO SUDDENLY. SHE FEELS HUGE FORCES IN HER LEGS! OW!

CRACK

BETTER TO DO IT WITH KNEES BENT, ROLLING TO PROLONG THE TIME OF IMPACT, REDUCING THE FORCES.



# CONSERVATION OF MOMENTUM

LET'S LOOK FOR A  
MINUTE AT COLLISIONS  
AND EXPLOSIONS. BY  
THIS WE MEAN ANY  
SITUATION WHERE  
THINGS ARE COMING  
TOGETHER OR  
FLYING APART.



COLLISION ABOUT TO HAPPEN



EXPLOSION ABOUT  
TO HAPPEN

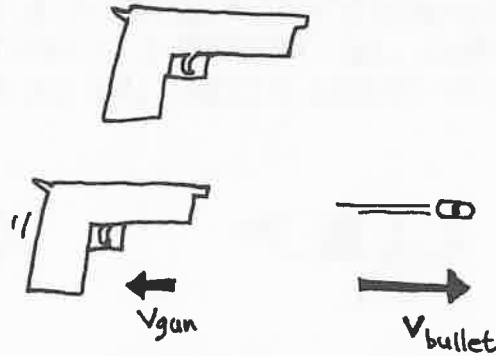
FOR EXAMPLE, CONSIDER SHOOTING A GUN. THIS IS AN EXPLOSION, IN THE GENERAL SENSE THAT THE BULLET GOES ONE WAY AND THE GUN RECOILS THE OTHER. SUPPOSE, FOR THE SAKE OF SIMPLIFYING THE ARGUMENT, THAT THE BULLET IS EJECTED BY MEANS OF A SPRING:



WHEN THE SPRING IS RELEASED, IT EXERTS A FORCE ON THE BULLET. BY NEWTON'S THIRD LAW, THE BULLET EXERTS AN EQUAL BUT OPPOSITE FORCE ON THE SPRING/GUN SYSTEM. THESE FORCES PRODUCE EQUAL BUT OPPOSITE CHANGES IN MOMENTUM. SINCE THE GUN IS MORE MASSIVE THAN THE BULLET, IT RECOILS AT A VELOCITY MUCH SMALLER THAN THE BULLET'S VELOCITY.



IN THIS CASE, THERE WAS NO NET CHANGE IN MOMENTUM. IF THE GUN AND BULLET WERE INITIALLY AT REST, THE MOMENTUM WAS ZERO AT FIRST. SINCE THE SPRING RELEASE DID NOT CHANGE THE TOTAL MOMENTUM, THE FINAL MOMENTUM IS ALSO ZERO: THE BULLET AND GUN HAVE EQUAL AND OPPOSITE MOMENTUM.



TOTAL MOMENTUM IS THE SAME BEFORE AND AFTER FIRING

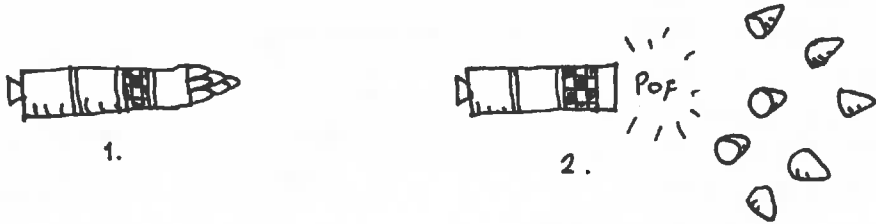


AFTER A LITTLE DISCUSSION, SCIENTISTS FOUND A PROPERLY SCIENTIFIC WAY TO SAY, "MOMENTUM DOESN'T CHANGE."

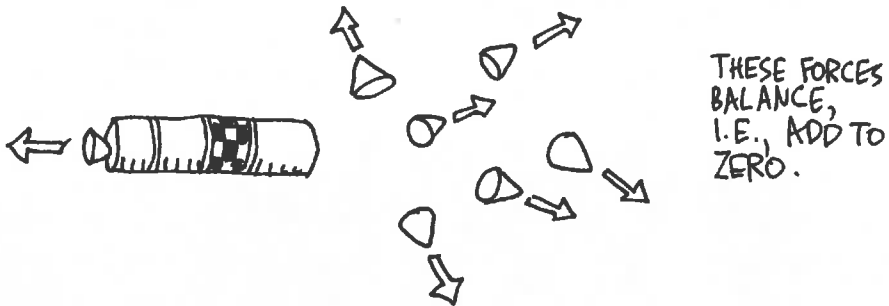
**MOMENTUM IS  
CONSERVED.**



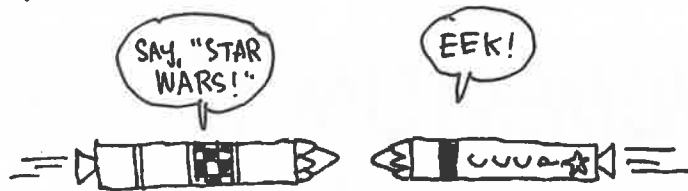
CONSERVATION OF MOMENTUM IS A CONSEQUENCE OF NEWTON'S THIRD LAW. CONSIDER A FLYING PROJECTILE THAT EXPLODES INTO SEVERAL PIECES, LIKE THIS MULTIPLE-WARHEAD MISSILE:



THE FORCES BETWEEN THE PIECES WE CALL **INTERNAL FORCES**. (THERE MAY ALSO BE EXTERNAL FORCES, SUCH AS GRAVITY.) BY NEWTON'S THIRD LAW, THE INTERNAL FORCES ACT IN EQUAL BUT OPPOSITE PAIRS. ANY FORCE ON ONE PIECE IS OFFSET BY AN EQUAL AND OPPOSITE FORCE ON ANOTHER PIECE.

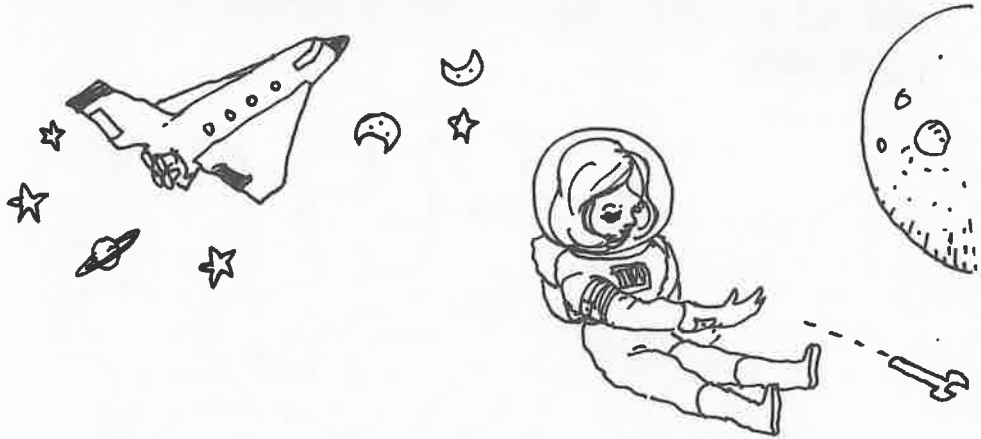


THEREFORE, THE INTERNAL FORCES CAN PRODUCE **NO NET CHANGE IN MOMENTUM**. EXPLOSIONS CONSERVE MOMENTUM.

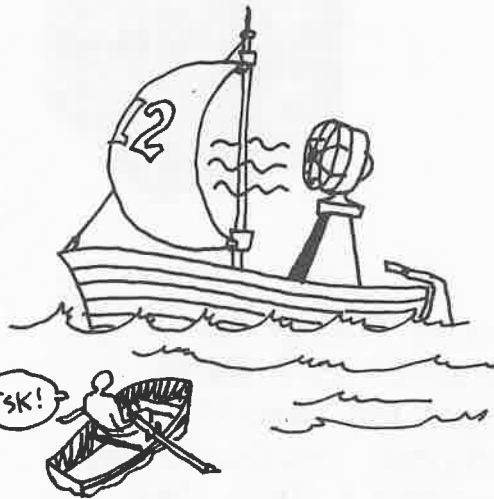


THE SAME ARGUMENT HOLDS FOR COLLISIONS, WHICH MIGHT BE CALLED EXPLOSIONS IN REVERSE.

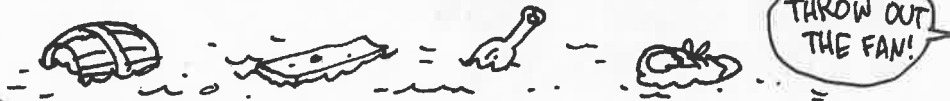
WE USED A ROCKET TO ILLUSTRATE NEWTON'S THIRD LAW, AND IT ALSO ILLUSTRATES CONSERVATION OF MOMENTUM. TO ACCELERATE IN SPACE, YOU MUST EJECT SOMETHING THE OTHER WAY — NAMELY, THE EXHAUST GASES. IF I'M SPACEWALKING, AND MY PROPELLANT SYSTEMS FAIL, HOW CAN I GET BACK? BY THROWING SOMETHING, SAY ONE OF MY TOOLS, IN THE OPPOSITE DIRECTION.



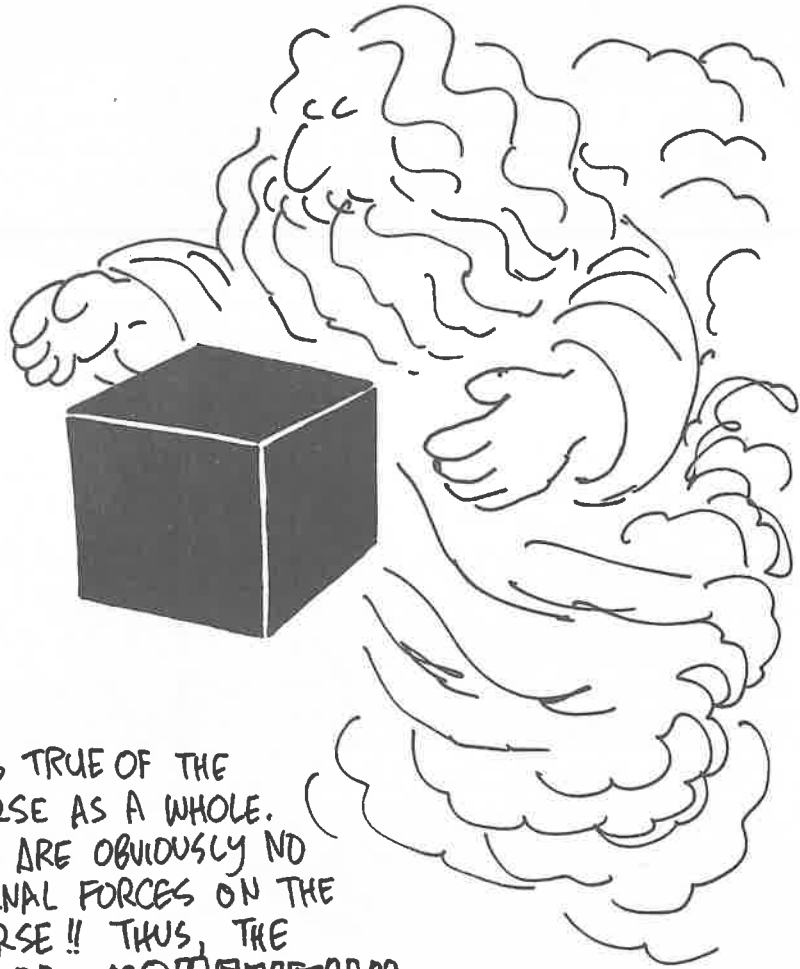
WILL THE FAN BLOWING ON THE SAIL MOVE THIS SAILBOAT? NO! (NOT UNLESS SOME OF THE WIND FROM THE FAN MISSES THE SAIL, OR BOUNCES OFF IT OUT THE OTHER WAY.)



SOMETHING MUST MOVE AWAY FROM THE SAILBOAT ONE WAY FOR IT TO BE PUSHED THE OTHER WAY.



MOMENTUM CONSERVATION WAS FIRST DERIVED FROM NEWTON'S THIRD LAW. BUT WE HAVE COME TO BELIEVE THAT CONSERVATION OF MOMENTUM IS THE MORE FUNDAMENTAL LAW, AND NEWTON'S LAW IS A CONSEQUENCE OF IT. IN ANY CLOSED SYSTEM, BY DEFINITION, THERE ARE NO EXTERNAL FORCES, SO MOMENTUM IS CONSERVED.



THIS IS TRUE OF THE UNIVERSE AS A WHOLE. THERE ARE OBVIOUSLY NO EXTERNAL FORCES ON THE UNIVERSE !! THUS, THE **TOTAL MOMENTUM IN THE UNIVERSE IS CONSTANT.**